Satellite Dynamics About Asteroids

D.J. Scheeres
Jet Propulsion Laboratory/Caltech

The study of orbital dynamics of a spacecraft about a non-spherical body has usually been restricted to the "planetary" case where the body is close to an oblate spheroid, with only a relatively small degree of equatorial ellipticity. When investigating spacecraft dynamics about asteroids, the situation becomes drastically different as the equatorial ellipticity may be the dominant feature of the body. For example, the Near Earth Asteroid Rendezvous (NEAR) mission has as its target the asteroid 433 Eros, with gross dimensions of 40.5 X 14.5 X 14.1 km and rotating about its largest moment of inertia with a period of 5.27 hours.

Clearly, the dynamical situation at such a body is far from the classical planetary case, and has only been investigated recently (B. Chauvineau, P. Farinella and F. Mignard, Icarus 105, 370- 384, 1994, and D.J. Scheeres, Icarus 110, 225 - 23S, 1994). One of the significant differences between the planetary case and the asteroid case is the possibility in the asteroid case for all the 1:1 resonance orbits to be unstable, which leads to the chaotic dynamics of nearly all pro-grade orbits within ~ 2 radii of such an asteroid.

An asteroid rotating in principal axis rotation is directly classifiable as a 3DOF Hamiltonian system when developed in the body-fixed frame. This classification holds no matter the degree of irregularity or lack of symmetry in the potential gravity field, due to the time-invariance of the body-fixed dynamical system. Then, given a gravity field and rotation rate, a number of classical analyses may be made of such a system: equilibrium points and their stability classification, zero-velocity surfaces, periodic orbits with continuously varying periods and their stability (including out-of-plane families), as well as some approximate relations and results of astronomical interest. (Available for viewing at the conference will be a video showing some of the orbital dynamics of a particle about the asteroid 4769 Castalia.)

If the asteroid is not in principal axis rotation, but has significant, precession and nutation, the orbital dynamics about it may be classified as a 4DOF Hamiltonian system when developed in the body-fixed frame. The 4th degree of freedom is the time, with its conjugate momentum being the previously constant Hamiltonian function of the 3DOF case. Now the governing equations of motion are time-periodic, as torque-free rigid body rotation is periodic in the body-fixed frame. In the transition from a uniformly rotating asteroid to an asteroid with nutation and precession, equilibrium points become periodic orbits with the period of the equations of motion, and the families of periodic orbits with continuously varying period break apart into, at best, quasi-periodic orbits with isolated periodic orbits with periods commensurate to the fundamental system period. Of interest for such a system is the following question: is it more fruitful to view the system as a 4DOF Hamiltonian system or as a 3DOF time-periodic Hamiltonian system.

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.